

# California High-Speed Train Project



## TECHNICAL MEMORANDUM

### EIR/EIS Assessment of CHST Alignment EMF Footprint TM 300.07

|              |  |                              |
|--------------|--|------------------------------|
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California High-Speed Train Project

# EIR/EIS Assessment of CHST Alignment EMF Footprint

**Revision 0  
February 27, 2012**

**prepared by**

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## Revision History

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| February 27, 2012 | 0   | Initial release |

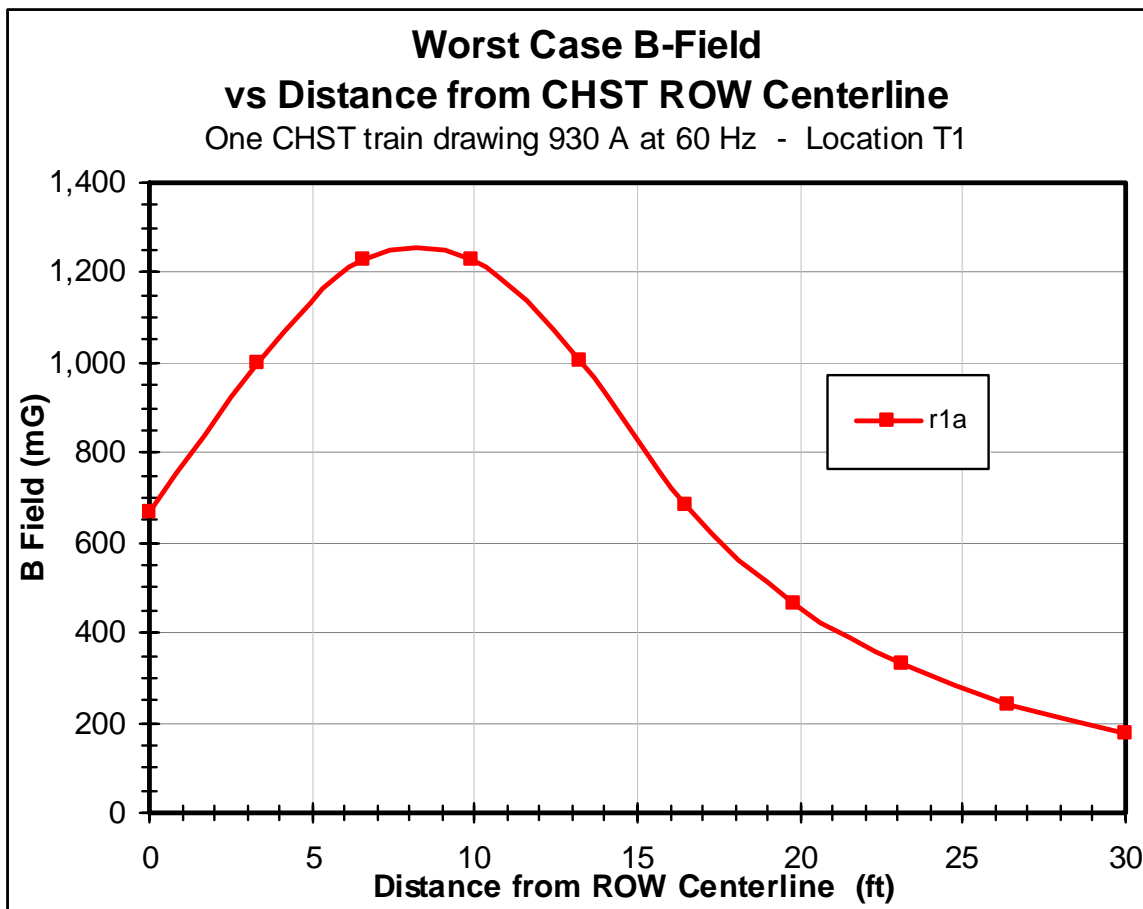


## Executive Summary

This *EIR/EIS Assessment of CHST Alignment EMF Footprint* report assesses the width of the corridor surrounding the California High-Speed Train (CHST) tracks in which the ambient electromagnetic field (EMF) will be affected by CHST operation. Each Regional Consultant will measure magnetic and electric fields in their section, apply the EMF team footprint to its section alignment, assess the potential impact of the EMF footprint on neighbors, and develop the section electromagnetic compatibility (EMC) Impact Assessment portions of the EIR/EIS Reports.

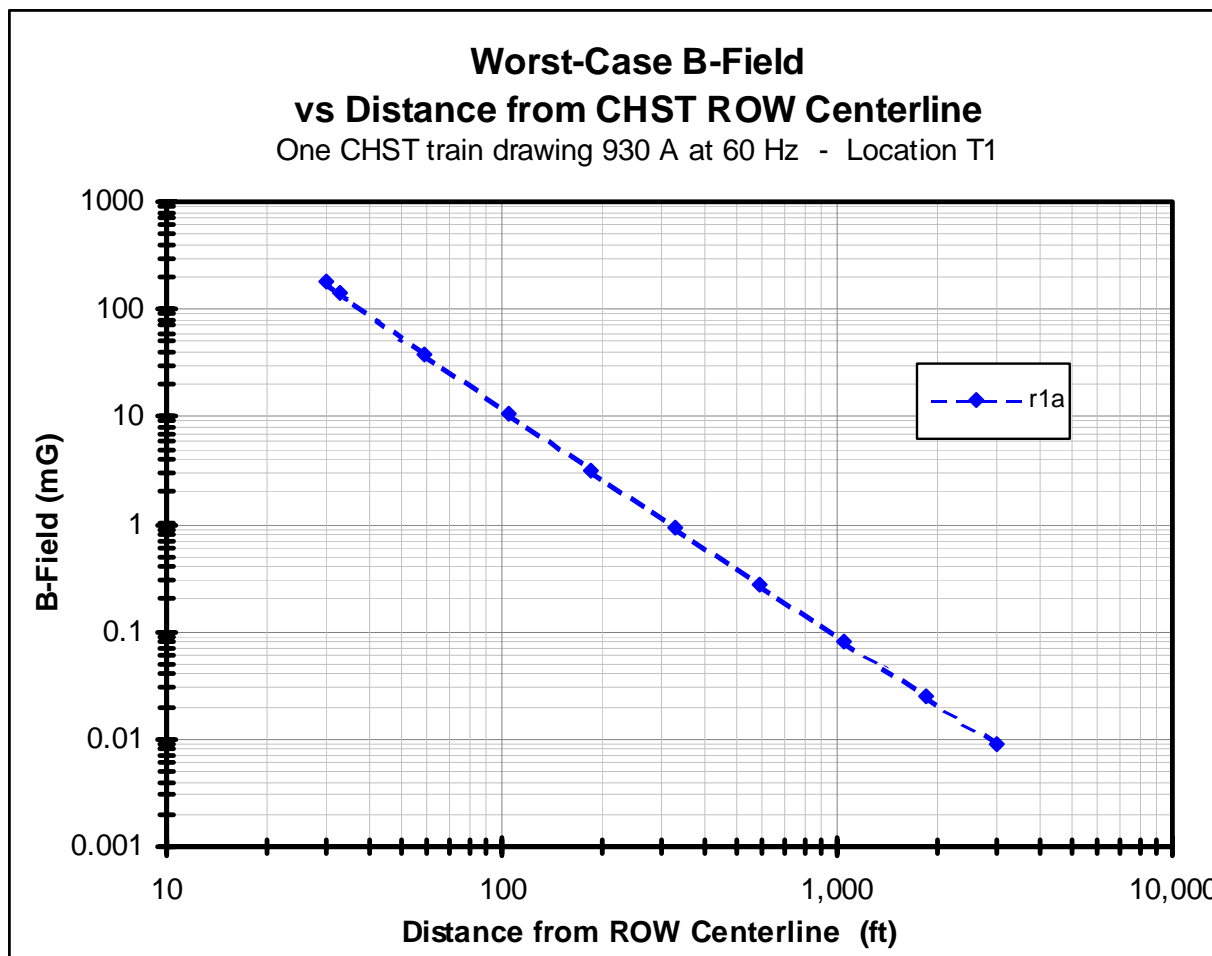
Figures E-1a and E-1b show the estimated worst-case 60 Hz magnetic field (B-field) caused by a CHST train vs. perpendicular distance from the center of the CHST right-of-way (ROW). The CHST train draws a maximum of 930 A at 60 Hz. Figure E-1a shows the peak B-field level vs. lateral distance from the ROW centerline, at a track location close to a traction power substation. The peak in the graph is at the centerline of the track containing the train. Figure E-1b shows the peak B-field level at greater lateral distances from the track, on a log-log scale. As CHST trains run down the track, the worst-case peak B-field condition is not prolonged in time or space. This is because train current does not remain at a peak level under all operating conditions, and because currents split between two tracks, between running rails and negative feeder, and between current paths to the front and rear as the train proceeds down the line.

**Figure E-1a Worst-Case B-Field Due to a 930 A train, Close to the Track**



At 60 Hz, the frequency of the CHST Traction Electrification System, the applicable standard governing human exposure to magnetic fields provides a maximum permissible exposure (MPE) limit of 9.0 G for the general public. Figure E-1a shows that a person standing on a CHST station platform about 2 feet from the platform edge, at about 8 feet from the track centerline or 16 feet from the ROW centerline, would be exposed to a B-field of about 720 mG. Thus, the CHST worst-case exposure is about 7.9% of the applicable MPE limit.

**Figure E-1b Worst-Case B-Field Due to a 930 A Train, Farther From the Track**



Whether neighbors will be disturbed by CHST B-fields depends on the equipment in use by neighbors and how the equipment is protected.

- Older unshielded hospital magnetic resonance imaging machines (MRI) can be disturbed by magnetic fields in the range of 1 to 3 mG. Shielded MRIs are probably immune to power frequency B-fields of up to 100 mG.



- Specialized scientific equipment such as nuclear magnetic resonance (NMR) instruments, scanning electron microscopes (SEM), and transmission electron microscopes (TEM) require stray magnetic fields to be below 0.1 to 0.3 mG to avoid interference. Typical NMR, SEM, and TEM equipment is installed in well-shielded facilities to protect against utility power line B-fields. NMR, SEM, and TEM equipment can be shielded to achieve immunity to power frequency B-fields of 10 mG or more.
- Most other equipment is unaffected by B-fields of less than 1 G.

Figure E-1a shows that the worst-case single train B-field is:

- 177 mG at 30 feet from the ROW centerline, the minimum CHST fenceline
- 100 mG at 37 feet from the ROW centerline, 7 feet from the minimum CHST fenceline
- 10 mG at 105 feet from the ROW centerline, 75 feet from the minimum fenceline
- 2 mG at 226 feet from the ROW centerline, 194 feet from the minimum fenceline.

Even the most sensitive equipment, if shielded, will be unaffected by CHST magnetic fields at 105 feet or more from the ROW centerline. Considering the likely locations of facilities containing sensitive equipment and the normal practices for shielding valuable sensitive equipment, shielded equipment will probably not be exposed to CHST magnetic fields strong enough to interfere with its operation.



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# EIR/EIS Assessment of CHST Alignment EMF Footprint

## 1 Introduction

The California High-Speed Train Project (CHSTP) established the electromagnetic compatibility (EMC) requirement that the California High-Speed Train (CHST) equipment and facilities must be electromagnetically compatible with themselves, with equipment used on and near CHSTP trains by staff and passengers, and with the equipment and facilities of the neighbors of the CHST line. CHST equipment and facilities must work with and not interfere with neighboring equipment and facilities, or the CHST project must provide mitigations which reduce interference with neighboring equipment and facilities to acceptable levels.

The Project Management Team (PMT) is responsible for design of CHST systems having EMC impact, including communications, train control, traction electrification, rolling stock, and station and facility equipment. The PMT is responsible for the project-level EMC program.

Regional Consultant teams are responsible for civil design and construction, and installation and integration of some system equipment with EMC impact, which may include communications, train control, traction electrification, and station equipment. Each CHSTP Regional Consultant is responsible for EMC engineering for their respective section.

Project-wide EMC design requirements are provided in the EMC Program Plan, Engineering Management Team Technical Memorandum 300.02. EMC design are provided in the EMC chapter of the Design Manual.

CHSTP section designers need EMC information to prepare the Section impact assessments for the CHST project Environmental Impact Report/Impact Study (EIR/EIS). For EIR/EIS-specific EMC information, the Section Designers must perform Radiated Electric and Magnetic Field measurements for each Section. The PMT prepared Technical Memorandum (TM) 3.4.11, Measurement Procedure for EIR/EIS Assessment of CHSTP Alignment EMF Footprint (MPE), to guide section designers so they can:

- Prepare a Section-Level Measurement Procedure For EIR/EIS Assessment Of CHSTP Alignment EMF Footprint (S-MPE) consistent with the MPE
- Perform the section-level measurements and data collection
- Provide a report with information needed for the section EIR/EIS and for the project.

This EIR/EIS Assessment of CHST Alignment EMF Footprint report uses the CHST Traction Electrification System (TES) characteristics to assess the width of the corridor surrounding the CHST tracks in which the ambient electromagnetic field (EMF) will be increased due to CHST operation. This is the CHST magnetic field ‘footprint’.

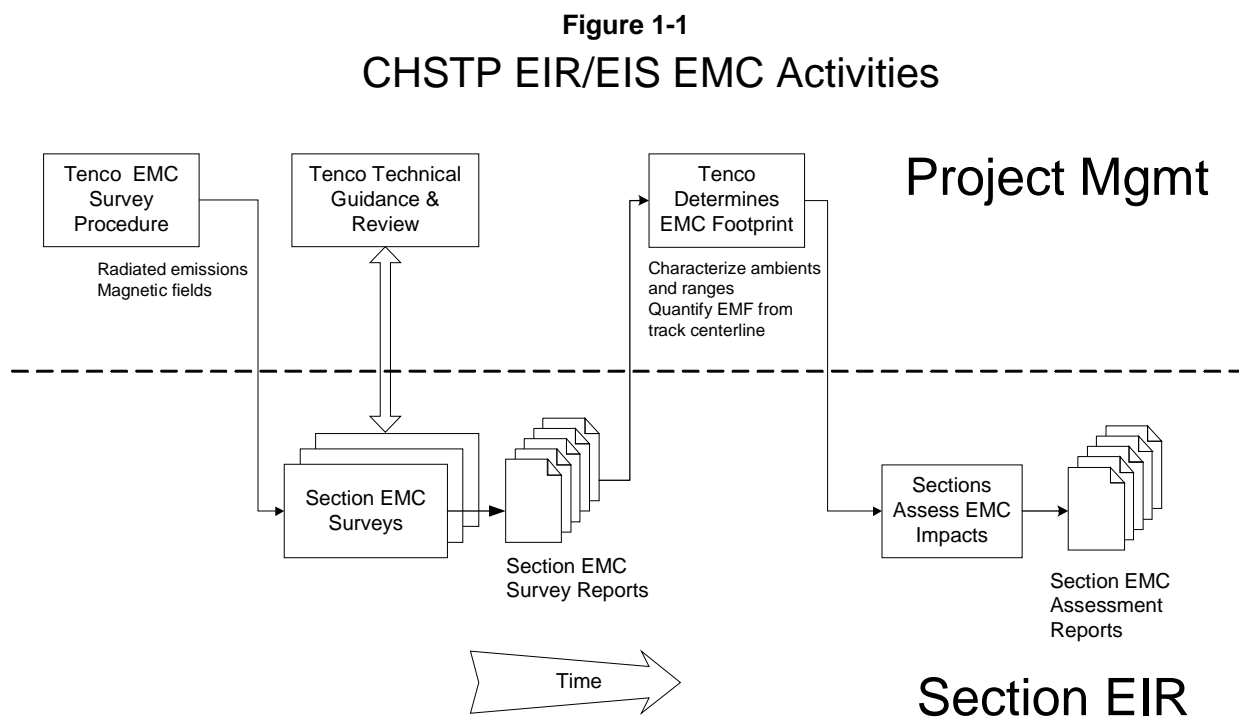




Each Regional Consultant team will measure magnetic and electric fields in their section, apply the EMF footprint to its section alignment, assess the potential impact of the CHST EMF footprint on neighbors, and develop the section electromagnetic compatibility (EMC) Impact Assessment portions of the EIR/EIS Reports.

## 1.1 CHST EIR/EIS Phase EMC Tasks

Figure 1-1 shows the near-term Project and Section EMC activities for the EIR/EIS Phase.



EIR/EIS Phase EMC tasks are:

- Task 1: Collect Section EMC data
- Task 2: Determine the areas of EMC influence in each Section.

Table 1-1 below shows tasks and status:

| Table 1-1: EIR/EIS Phase EMC Task Status |   |   |
|--|---|---|
| ID                                       | Task  | Status  |
| 1.1                                      | Tenco develops the EIR/EIS Section EMC survey procedure (MPE)   | Complete. See TM 3.4.11                             |
| 1.2                                      | Each Section develops an EMF Footprint Measurement Procedure (S-MPE). Select the Section EMI measurement sites. | Sections are preparing for and making measurements. |



**Table 1-1: EIR/EIS Phase EMC Task Status**

| ID  | Task   | Status  |
|-----|--|---|
| 1.3 | Each section performs the Section EMI measurements. Establish the baseline electromagnetic ambient and identify worst-case wayside emitters and susceptibility victims. Provide a report.                | Sections are preparing reports.                     |
| 2.1 | Tenco to use the Section survey data, perform analysis, and develop the project-wide CHST EMC footprint - expected emission impact vs. distance from track centerline vs. frequency.                     | This report is the task 2.1 result.                 |
| 2.2 | Each Regional Consultant team applies the 'footprint' to Section alignments to assess the potential impact of the CHST EMC footprint on neighbors and develop the Section EMC Impact Assessment Reports. | Sections are making the assessment for the EIR/EIS. |

## 1.2 Overview of the MPE Measurement Procedure

The MPE, TM 3.4.11, guides Section development of a test method, test arrangement, and related technical information for performing the Section EMF Footprint Measurements. The MPE also describes the format of the measurement results documentation.

Each Section EMF Footprint Measurements will consist of:

- Radiated electric field measurements
- Magnetic field measurements.

**Radiated Electric Field Measurements:** Each Regional Consultant measurement team will perform and document radiated measurements using techniques from the Radiated Interference in Rapid Transit Systems, Volume II: Suggested Test Procedures, UMTA-MA-06-0153-85-11, method RT/RE01A, "Broadband Emissions of Rapid Transit Vehicles - 140 kHz to 400 MHz" (RSTP). The Regional Consultant will measure from 10 kHz to 6.0 GHz, using a RF Spectrum Analyzer and calibrated antennas. The measurements will use the bands in the following Table 1-2.

**Table 1-2  
Radiated Emissions Measurement Bands**

| ID | Frequency Range   | Antenna         | Ant Orientation | Resolution Bandwidth |
|----|-------------------|-----------------|-----------------|----------------------|
| B0 | 10 kHz – 50 kHz   | Active Monopole | Vertical        | 1 or 3 kHz           |
| B1 | 50 kHz – 550 kHz  | Active Monopole | Vertical        | 10 kHz               |
| B2 | 500 kHz – 3 MHz   | Active Monopole | Vertical        | 10 kHz               |
| B3 | 2.5 MHz – 7.5 MHz | Active Monopole | Vertical        | 10 kHz               |



| <b>Table 1-2</b><br><b>Radiated Emissions Measurement Bands</b> |                   |                 |                 |                      |
|---|-------------------|-----------------|-----------------|----------------------|
| ID  | Frequency Range   | Antenna         | Ant Orientation | Resolution Bandwidth |
| B4  | 5 MHz – 30 MHz    | Active Monopole | Vertical        | 100 kHz              |
| B5h   | 25 MHz – 225 MHz  | Biological      | Horizontal      | 100 kHz              |
| B5v   | 25 MHz – 225 MHz  | Biological      | Vertical        | 100 kHz              |
| B6h   | 200 MHz – 2.2 GHz | Biological      | Horizontal      | 300 kHz              |
| B6v   | 200 MHz – 2.2 GHz | Biological      | Vertical        | 300 kHz              |
| B7h   | 2 GHz – 6 GHz     | Biological      | Horizontal      | 300 kHz              |
| B7v   | 2 GHz – 6 GHz     | Biological      | Vertical        | 300 kHz              |

**Magnetic Field Measurements:** Each Section measurement team will perform and document magnetic field measurements using a sensitive magnetometer. The team will measure from DC to 800 Hz, using an AlphaLab three axis magnetometer and magnetic field probe, or equivalent.

### 1.3 Reference Information

Table 1-3 lists acronyms and abbreviations used in this report.

| <b>Table 1-3 Acronyms and Abbreviations</b> |  |
|---|--|
| ac  | alternating current                    |
| A   | ampere                                 |
| Authority                                   | California High-Speed Rail Authority   |
| B-field                                     | Magnetic field                         |
| CFR   | Code of Federal Regulations            |
| CHST  | California High-Speed Train            |
| CHSTP                                       | California High-Speed Train Project    |
| CPUC  | California Public Utilities Commission |
| dc  | direct current                         |
| EIR   | Environmental Impact Report            |
| EIS   | Environmental Impact Study             |
| EMC   | Electromagnetic compatibility          |
| EMCP  | CHST EMC Plan                          |
| EMF   | Electromagnetic field                  |
| EMI   | Electromagnetic interference           |
| EN  | Euro Norm                              |
| FCC   | Federal Communications Commission      |
| ft  | Feet                                   |



| <b>Table 1-3 Acronyms and Abbreviations</b> |  |
|---|--|
| FRA   | Federal Railroad Administration  |
| G   | gauss  |
| GHz   | gigahertz  |
| GO  | General Order  |
| Hz  | hertz  |
| FCC   | Federal Communications Commission  |
| IEEE  | Institute of Electrical and Electronic Engineers   |
| kHz   | kilohertz  |
| mG  | milligauss   |
| MPE   | Maximum permissible exposure.<br>Also, EIR/EIS Measurement Procedure for Assessment of CHSTP Alignment EMI Footprint, TM 3.4.11  |
| MRI   | Magnetic resonance imaging machine   |
| NMR   | Nuclear magnetic resonance   |
| OCS   | Overhead Contact System  |
| PMT   | Project Management Team  |
| PS  | Traction Power Paralleling Station   |
| ROW   | Right of way   |
| RSTP  | Radiated Interference in Rapid Transit Systems, Volume II: Suggested Test Procedures, UMTA-MA-06-0153-85-11, method RT/RE01A, "Broadband Emissions of Rapid Transit Vehicles - 140 kHz to 400 MHz" |
| SCE   | Southern California Edison   |
| SEM   | Scanning electron microscope   |
| S-MPE                                       | Section Measurement Procedure for Assessment of CHSTP Alignment EMI Footprint  |
| SS  | Traction Power Switching Station   |
| TEM   | Transmission electron microscope   |
| TES   | Traction Electrification System  |
| TM  | Technical memorandum   |

Table 1-4 lists reference documents.

| <b>Table 1-4 CHSTP EMC Program Reference Information</b> |                  |  |
|--|------------------|--|
| <b>ID</b>  | <b>Issued By</b> | <b>Title</b>   |
| GO 95  | CPUC             | California Public Utilities Commission General Order 95, Overhead Electric Line Construction   |
| GO 131   | CPUC             | California Public Utilities Commission General Order 131, Rules Relating to the Planning and Construction of Electric Generation, Transmission/Power/Distribution Line Facilities and Substations Located in California. |
| FCC OET-65   | FCC              | Evaluating Compliance with FCC Guidelines for Human Exposure to Radio frequency Electromagnetic Fields, FCC Office of Engineering and Technology Bulletin 65, Edition 97-10  |
| FCC Part 15  | FCC              | Part 15 of Title 47 of the Code of Federal Regulations   |
| DOT-VNTSC-FRA-05-05                                      | FRA              | EMF Monitoring on Amtrak's Northeast Corridor: Post-Electrification Measurements and Analysis, October 2006  |



| Table 1-4 CHSTP EMC Program Reference Information |           |   |
|---|-----------|---|
| ID  | Issued By | Title   |
| UMTA-MA-06-0153-85-11                             | FTA       | Radiated Interference in Rapid Transit Signaling Systems - Volume II: Suggested Test Procedures           |
| IEEE Std C95.1-2005                               | IEEE      | IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 3 kHz - 300 GHz |
| IEEE Std C95.6-2002                               | IEEE      | IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 - 3 kHz       |
|   | PG&E      | Pacific Gas & Electric Company Transmission Line EMF Design Guidelines, May 1994                          |
|   | SCE       | Southern California Edison EMF Design Guidelines For Electrical Facilities, September 2004                |
| MIL-STD-461F                                      | USDOD     | Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference  |
| EMCP  | Authority | CHSTP Planning Stage EMC Program Plan, Revision 1.1, September 22, 2010, EMT TM 300.02                    |

## 1.4 Contents of This Report

Following sections of this report are:

Section 2 – Magnetic Field Footprint

Section 3 – Magnetic Field Calculation Model.



## 2 Magnetic Field Footprint

### 2.1 CHST Traction Electrification System

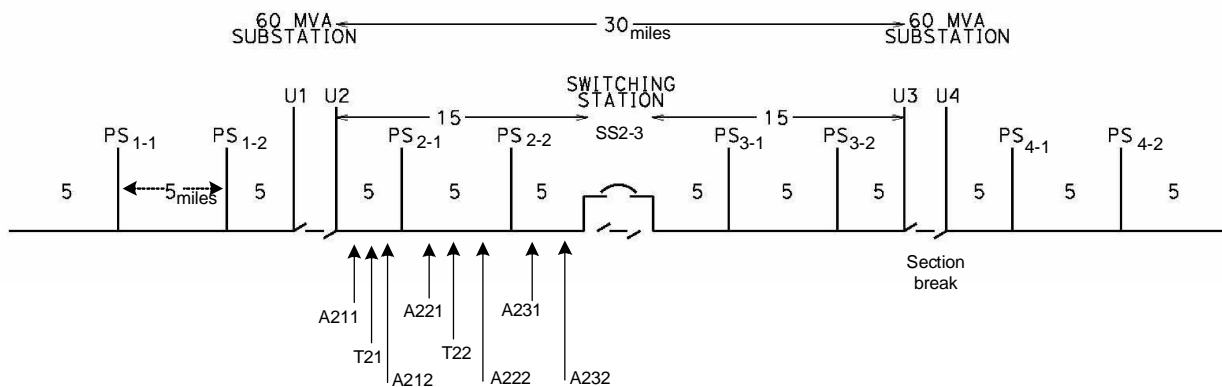
Tenco used the design characteristics of the CHST TES to assess the width of the magnetic field (B-field) footprint of the CHST right-of-way (ROW). The footprint width is the lateral distance along the ground from the ROW centerline to the point at which the CHST B-field from a single worst-case train falls to a level below the significance criterion. The significance criterion has been set at 2 mG; this is further discussed in section 2.8.

Figure 2-1a shows the CHST 2x25 kV 60 Hz Traction Electrification System (TES). Refer to TM 3.1.1.1, Traction Power 2x25kV Autotransformer Feed Type Electrification System and System Voltages. Figure 2-1a shows the typical arrangement of TES facilities for a 60-mile track section. Figure 2-1b shows details of a 15-mile section between a traction power substation (substation) and a switching station. The TES consists of:

- Traction power facilities:
  - Dual Substations every 30 miles. Each Substation normally feeds 15 miles of track. Substation U1, U2, U3 and U4 are shown.
  - Switching Stations (SS) every 15 miles. The SS in the middle of the figure is labeled SS2-2, since it is between substations U2 and U3.
  - Paralleling Stations (PS) every 5 miles. The PS going from U2 towards U3 are labeled PS2-1 and PS2-2, since they are the two PS in the U2 section.
- Section breaks at each Substation and SS.

Traction power is delivered to the trains via the overhead contact system (OCS) and running rails.

**Figure 2-1a CHST Traction Electrification System**



Key: PS = Paralleling Station. Numbers are distances in miles.

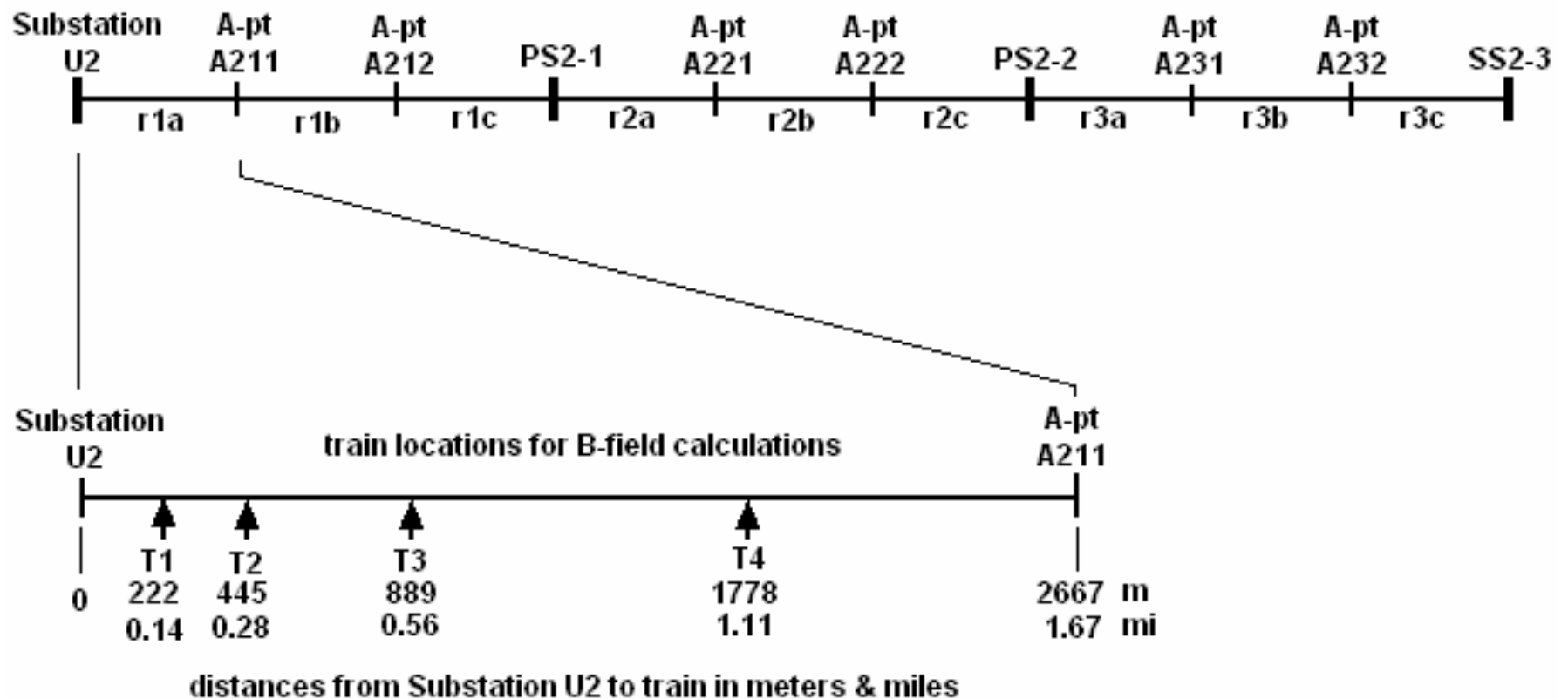


Figure 2-1b Section of CHST Traction Electrification System

**POINTS ALONG A CAL HST ROW SEGMENT AT WHICH B-FIELDS WERE CALCULATED**

Shown below is half of a 30 mi (48 km) section of ROW.

The other end of the segment looks like the half below transposed end-for-end.



PSs, SSs, and Substations each provide a connection between the static wire (aerial ground), running rails, and ground. The ground contact resistance is a maximum of 5 ohms, but is typically less than 1 ohm. The static wire is electrically connected to each catenary pole, and each catenary pole is grounded with a contact resistance specified to be less than 25 ohms, expected to be typically less than 5 ohms. The rails sit on insulated pads and the rail clips are insulated; resistance between running rails and ground is expected to be at the high end of the conventional range of 1 to 20 ohm-km.

The figures show “A-point” crossbond locations. A-points provide static wire-to-rail-to-ground connections. In the section between Substation U2 and SS2-3, there are two A-points between each traction power facility, every 1.67 miles. These are labeled, for example, A211, for the first A-point in the U2 section, in the first subsection after U2. Similarly, A222 is the second A-point in the second subsection of the U2 section. The actual spacing of “A-points” for the CHST line has not been finalized.

Since the running rails are connected to earth by A-points, some traction return current flows in the earth.

## 2.2 Train Characteristics

The specific characteristics of the train which will run on the CHST have not been finalized. For modeling, the CHSTP uses the characteristics of the highest current train presently in service, since that is the limiting case.

For this EMF Footprint Assessment, the train maximum current is taken to be 930 A for a 400 m, 16-car, maximum length train. The train typical operating current is expected to be 750 A for a 16-car maximum length train.

## 2.3 Train Cases

Tenco calculated the EMFs at several track locations for a 930 A train in several positions. The train locations T1, T2, etc., and the EMF calculation locations r1a, r1b, etc., are shown in Figure 2-1b. Table 2-1 shows the cases and the maximum of the calculated B-fields at the locations r1a, r1b, etc., along the track, when the train is at the listed distance from the Substation.

:

**Table 2-1**  
**CHST Single Train EMF Scenarios**

| Scenario | Substation-to-train distance (m) | Substation-to-train distance (ft) | Peak B-field (mG) | Sum of peak B-fields ahead of and behind train (mG) | Lateral distance for Bmax = 2 mG (m) | Lateral distance for Bmax = 2 mG (ft) |
|----------|----------------------------------|-----------------------------------|-------------------|---|--------------------------------------|---------------------------------------|
| T1       | 222                              | 728                               | 1,250             | 1,420   | 69                                   | 226                                   |
| T2       | 445                              | 1,460                             | 1,190             | 1,420   | 68                                   | 221                                   |
| T3       | 887                              | 2,910                             | 1,030             | 1,420   | 65                                   | 213                                   |
| T4       | 1,778                            | 5,833                             | 750               | 1,420   | 69                                   | 226                                   |





As the train moves away from the Substation, the currents in the OCS and rails divide in front of and behind the train. Since the currents cause the B-field, the B-field is greatest when the currents are concentrated on one end of the train. Consequently, the peak B-field is greatest for case when the train is closest to the Substation and the current is concentrated behind the train.

The table shows that the sum of the calculated peak B-fields in front of and behind the train are constant, regardless of the train location. This is consistent with the modeled condition in which current flows both to the front and the rear of the train, but the total current remains constant.

As discussed in section 3, CHST B-fields generally decrease at a rate approaching  $1/d^2$  for  $d$  greater than about 30 feet, where  $d$  is the lateral distance from the nearest CHST track centerline.

This report expresses magnetic fields in units of Gauss (G) and milligauss (mG), for clarity. For reference,  $1 \text{ G} = 1.0\text{E-}4 \text{ Tesla (T)}$ , and  $1 \text{ mG} = 1.0\text{E-}7 \text{ T}$ .

The right hand columns of Table 2-1 show “Lateral distance for  $B_{\text{max}} = 2 \text{ mG}$ ,” which is the lateral distance from the ROW centerline to the point where the B-field is less than the significance criterion of 2 mG. The lateral distance is about 215 to 235 feet for all the cases. This indicates that the division of currents in front of and behind the train does not significantly affect the B-field when the measurement point is relatively far from the ROW centerline.

Worst-case EMF conditions exist when:

- The measured location is close to the train.
- The train is operating at maximum line current of 930 A at 60 Hz. The single train model assumes the train draws this current continuously. In actual operation, train current is often lower than the maximum.
- Almost all the traction power current drawn through the overhead contact system (OCS) wires flows back to the nearby traction power facility through the rails; no current flows in the negative feeder. This condition occurs when the train is close to a traction power Substation.

Current distribution in the OCS wires and rails, and the resulting B-fields, depend on the locations of trains relative to autotransformers and main power transformers feeding the system. The model reflects these current distributions.

In actual operation of CHST trains, worst-case conditions are not prolonged, because train current does not remain at a peak level under all operating conditions such as medium speed, medium acceleration, and braking; and because currents split between two tracks, between running rails and negative feeder, and between current paths to the front and rear of the train as the train proceeds down the line.

In addition, CHST design criteria call for Substations to be positioned at least 2 miles from any passenger station. As shown in following figures, the maximum B-field at a location 2 miles from a Substation is considerably less than the worst-case B-field. Accordingly, passengers will not be exposed to worst-case B-fields on passenger station platforms.



### 2.3.1 Train Worst Case

Figures 2-2a and 2-2b show the worst-case B-field due to a single 930 A CHST train vs. perpendicular distance along the ground from the ROW centerline. This is for train location T1, with the train 758 feet (222 m) from Substation U2 in the direction of Switching Station SS2-3.

Figure 2-2a is a linear graph of B-field vs. distance close to the ROW centerline and Figure 2-2b is a log graph covering distances further from the ROW centerline. The B-field in the figure is for the line which crosses the track at location 'r1a' in Figure 2-1b, about 364 feet from Substation U2, behind the train at T1. The peak in the Figure 2-2a graph is at the centerline of the track containing the train. The calculation gives essentially identical results with Substation ground contact resistance of either 1 ohm or 5 ohm.

As further discussed below, at 60 Hz, the frequency of the CHST TES, the applicable IEEE Std C95.6 governing human exposure to magnetic fields provides a maximum permissible exposure (MPE) limit of 9.0 G for the general public. If a passenger station were placed close to a traction power Substation and if train maximum current was sustained, Figure 2-2a shows that a person standing on a CHST station platform about 2 feet from the platform edge, at about 8 feet from the track centerline or 16 feet from the ROW centerline, would be exposed to a B-field of about 720 mG. Thus, the CHST worst-case exposure is about 7.9% of the applicable MPE limit.

The figure shows that the worst-case single train B-field is:

- 177 mG at 30 feet from the ROW centerline, the minimum CHST fenceline
- 100 mG at 37 feet from the ROW centerline, 7 feet from the minimum CHST fenceline
- 10 mG at 105 feet from the ROW centerline, 75 feet from the minimum fenceline
- 2 mG at 226 feet from the ROW centerline, 194 feet from the minimum fenceline.

### 2.3.2 Other Train Locations

The cases for the train at locations T2, T3, and T4 have the same B-field levels at smaller distances from the ROW centerline. The results for these train locations are shown in Figures 2-3, 2-4, and 2-5.

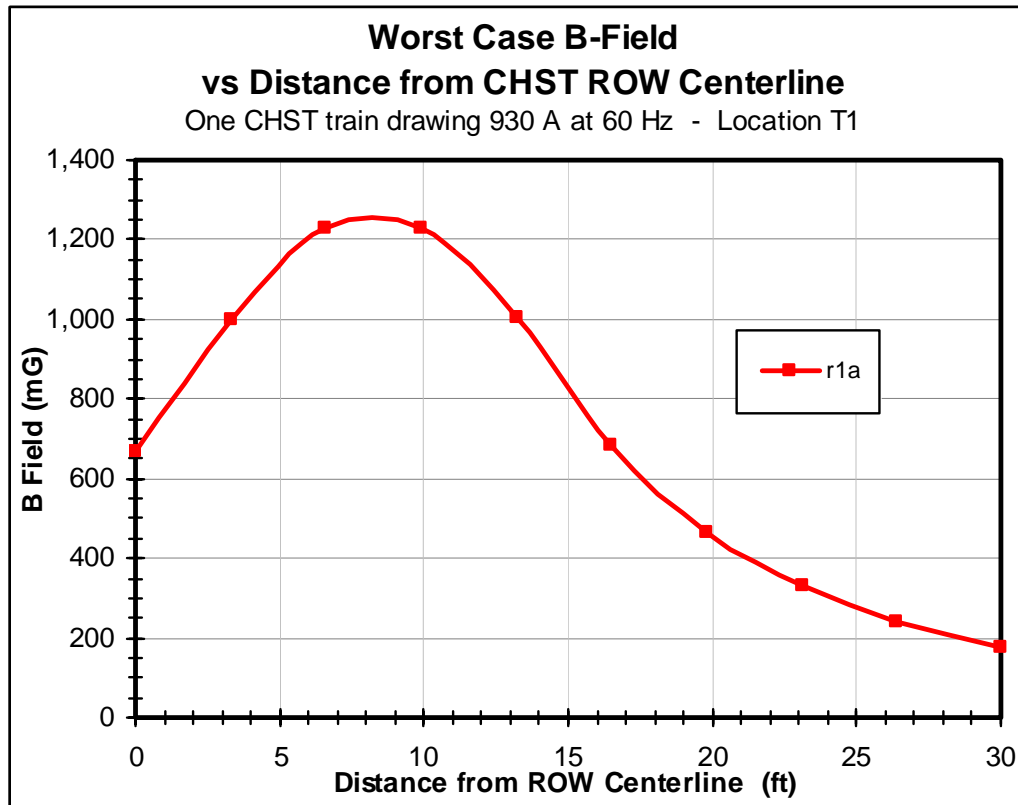
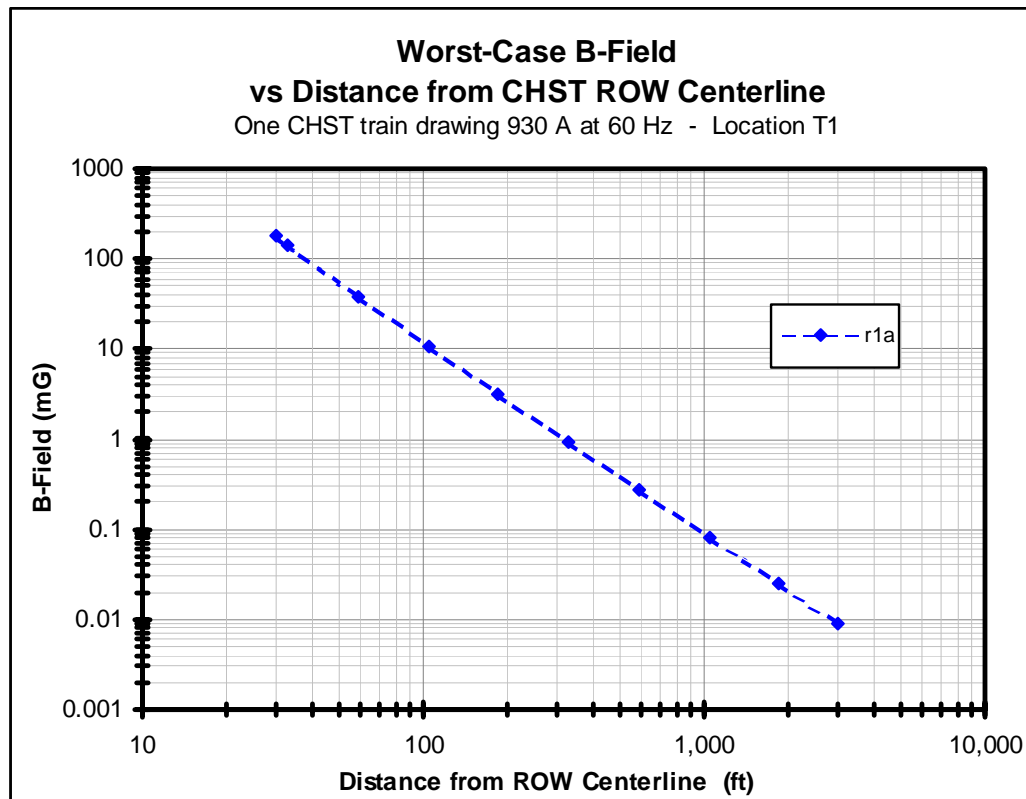
### 2.3.3 A-Point Spacing

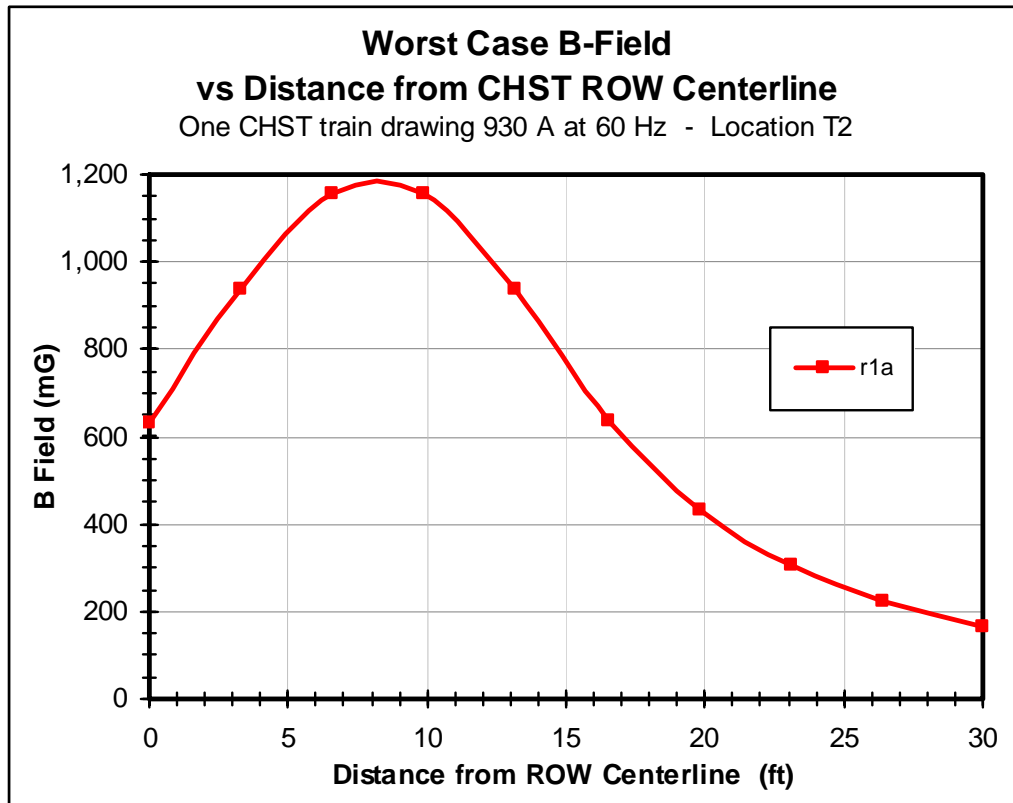
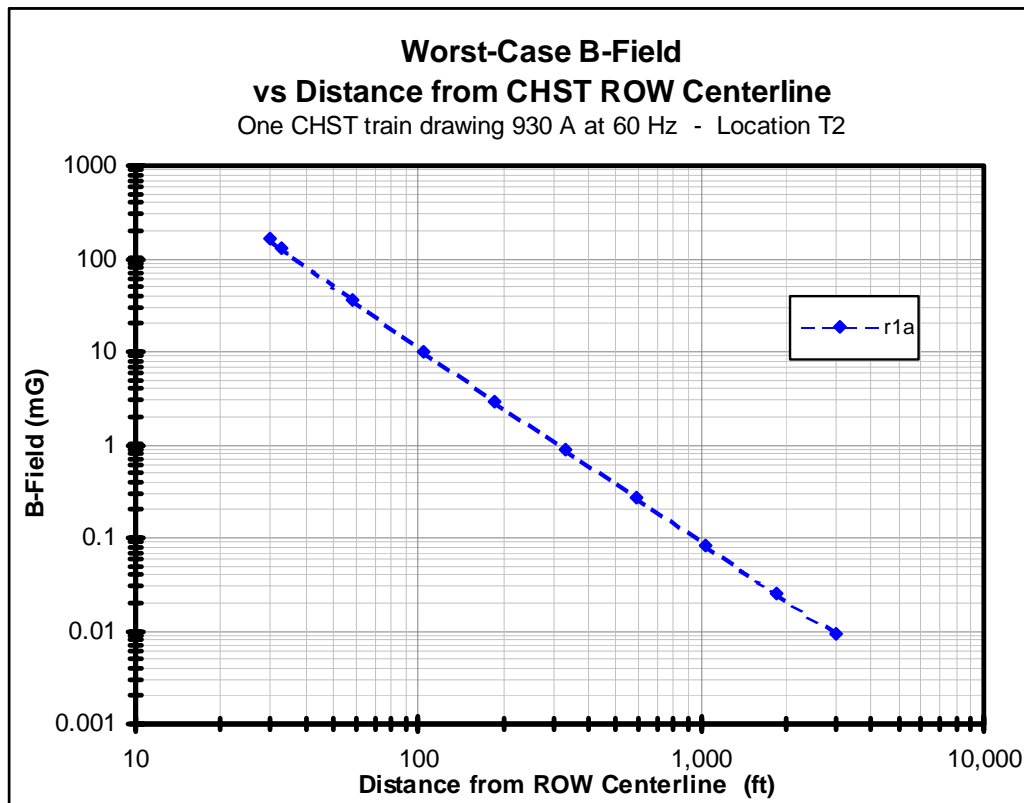
Figure 2-6 shows a similar case but with one A-point between traction power facilities at 2.5 mile spacing, rather than with two A-points at 1.67 mile spacing as in Figures 2-2 through 2-5. The train is at location T3. For comparison, the B-field at the station platform edge is:

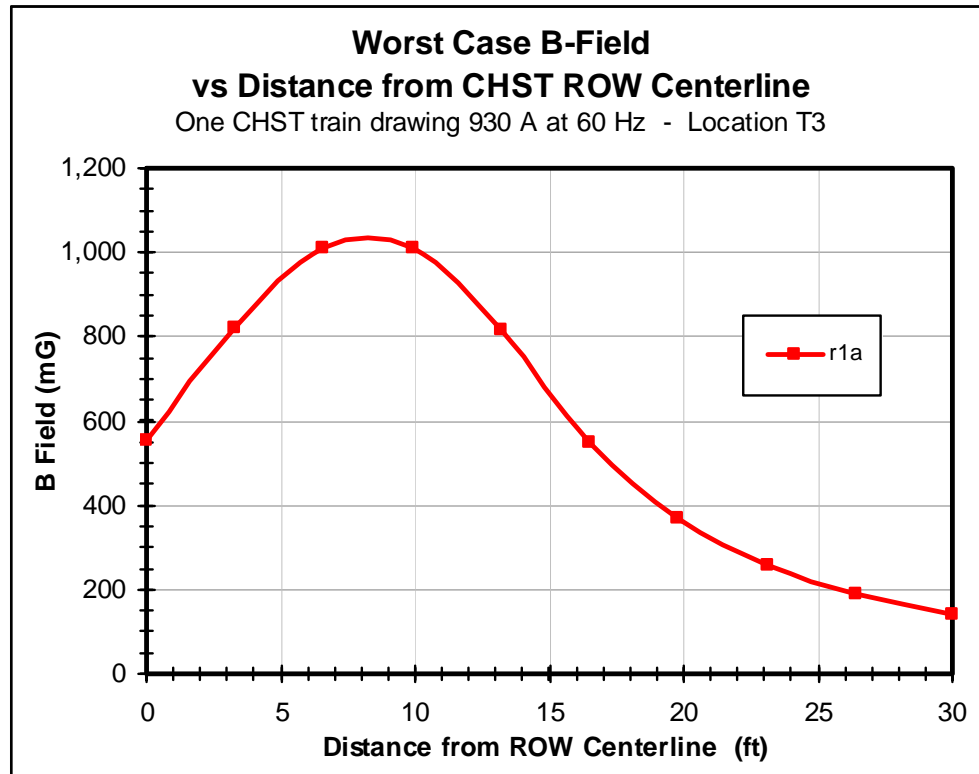
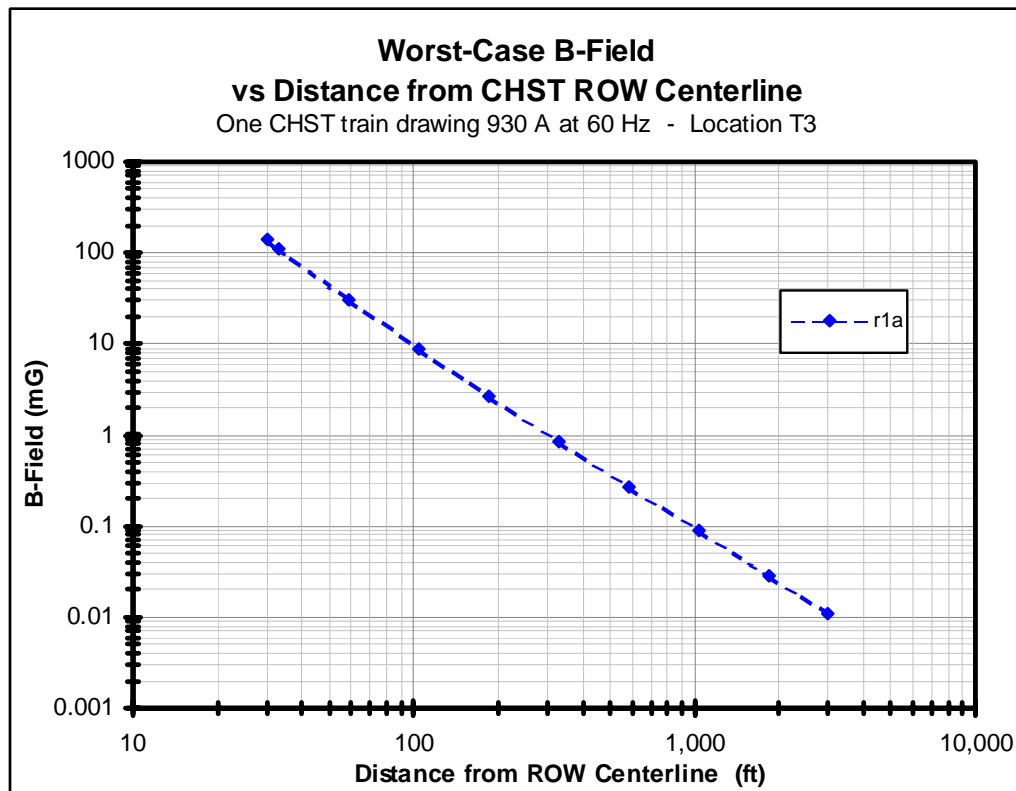
- With A-points at 1.67 mile spacing, Figure 2-4, 570 mG
- With A-points at 2.5 mile spacing, Figure 2-6, 635 mG.

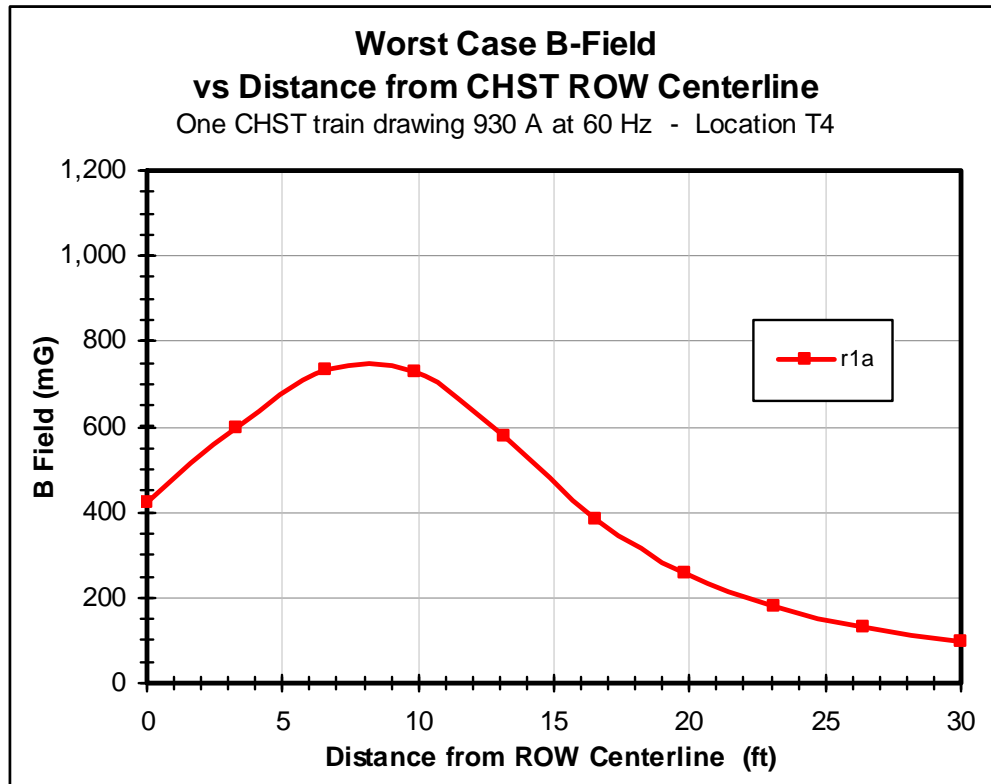
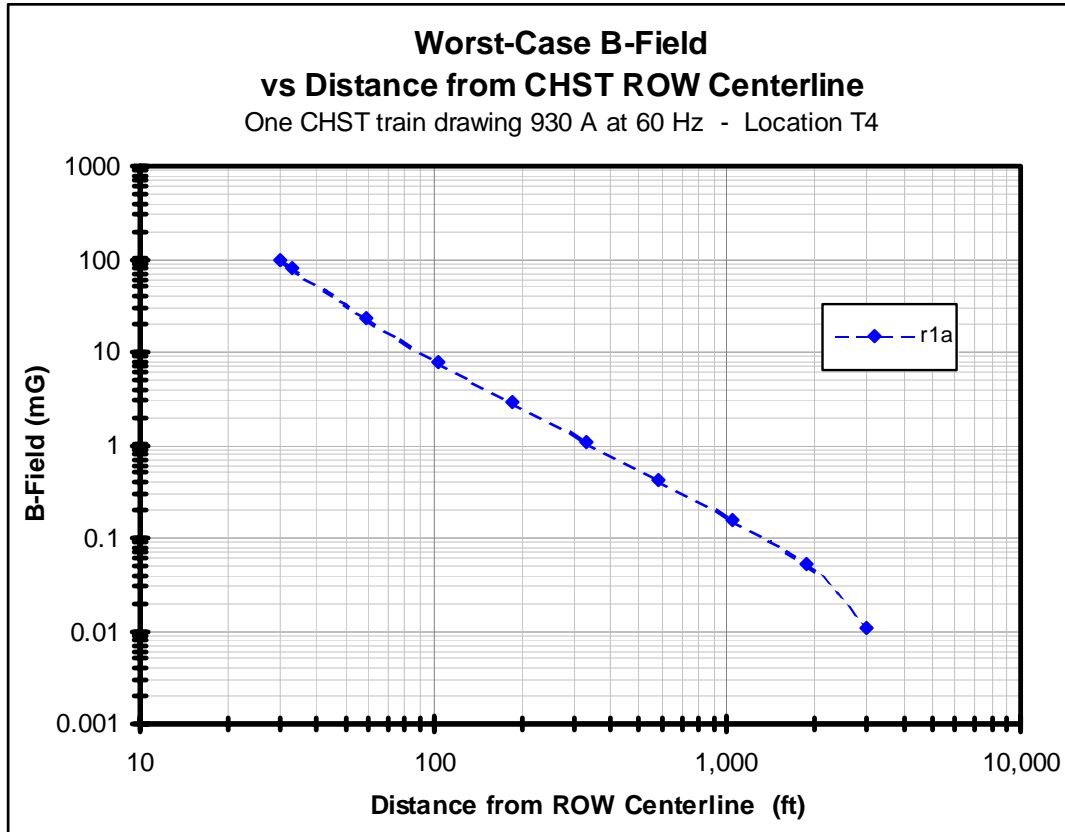
A-points at closer spacing incrementally reduce the peak B-field near the track carrying the train, probably by permitting more traction return current to flow in the rails of the opposite track and in the static wire rather than in the rails carrying the train.



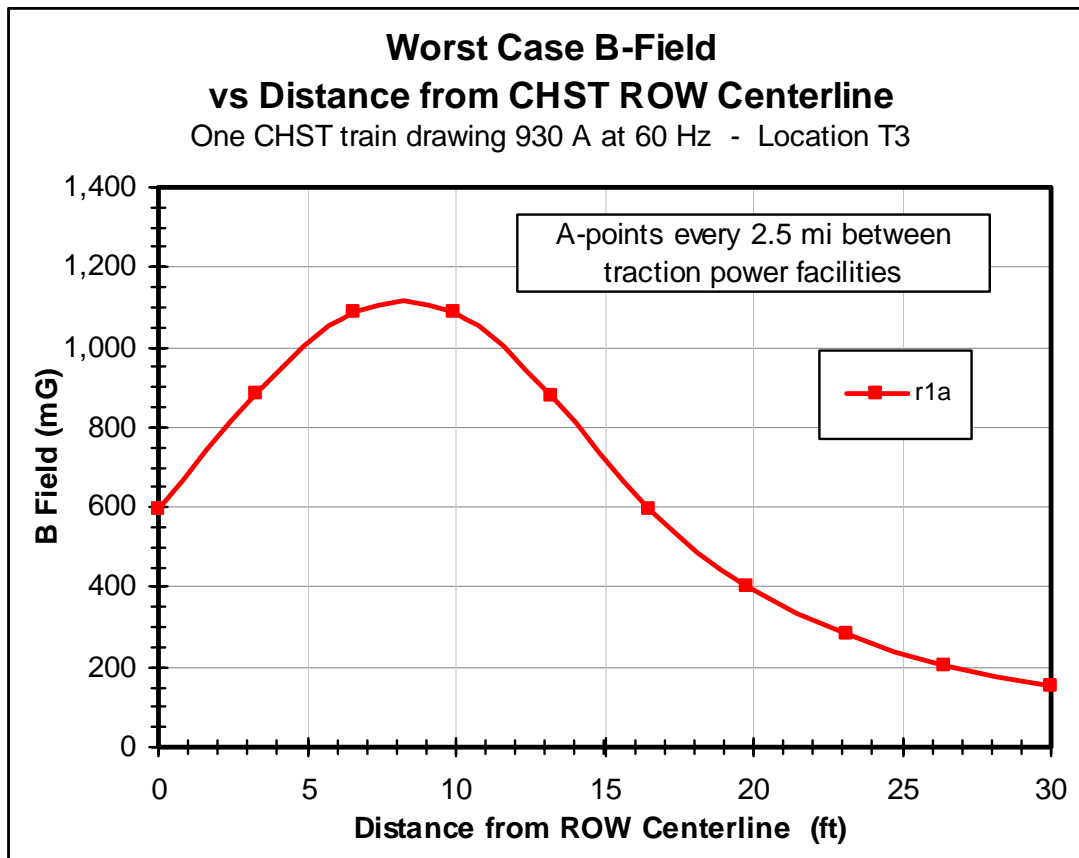
**Figure 2-2a Worst-Case B-Field Due to a 930 A Train at Location T1; B-Field Close to Track****Figure 2-2b Worst-Case B-Field Due to a 930 A Train at Location T1; B-Field Farther From Track**

**Figure 2-3a Worst-Case B-Field Due to a 930 A Train at Location T2; B-Field Close to Track****Figure 2-3b Worst-Case B-Field Due to a 930 A Train at Location T2; B-Field Farther From Track**

**Figure 2-4a Worst-Case B-Field Due to a 930 A Train at Location T3; B-Field Close to Track****Figure 2-4b Worst-Case B-Field Due to a 930 A Train at Location T3; B-Field Farther From Track**

**Figure 2-5a Worst-Case B-Field Due to a 930 A Train at Location T4; B-Field Close to Track****Figure 2-5b Worst-Case B-Field Due to a 930 A Train at Location T4; B-Field Farther From Track**

**Figure 2-6 Worst-Case B-Field Due to a 930 A Train at Location T3; A-points at 2.5 mi Intervals; B-Field Close to Track**



### 2.3.4 B-Field At Other Locations

Figures 2-2a and 2-2b shows the B-field at the worst-case calculation location, which is with the train closest to the Substation. This is the worst-case B-field condition. With the train at other locations further from the substation, and observing the EMF at other locations, the B-field levels are lower. Figure 2-7 shows the B-field levels at the other calculation locations in Figure 2-1b, with the train at the worst-case location T1 near the substation. The Figure 2-7a and 2-7b curves include the Figure 2-2a and 2-2b curves, for comparison.

Figure 2-7 shows that for a train in the worst-case location T1 drawing the maximum current:

- At small lateral distances (close to the ROW centerline), B-fields are dramatically lower at all the non-worst-case calculation locations than at the worst-case location. The B-fields are lower at the non-worst-case locations by two or more orders of magnitude (100x).
- At a lateral distance of around 230 feet from the ROW centerline (where the worst-case B-field is reduced to the significance criterion level of 2 mG), B-fields are significantly lower at all the non-worst-case calculation locations than at the worst-case location. The B-fields are lower at the non-worst-case locations by two to ten times or more.



Figure 2-7a B-Fields at Several Locations Due to a 930 A Train at Location T1;  
B-Field Close to Track

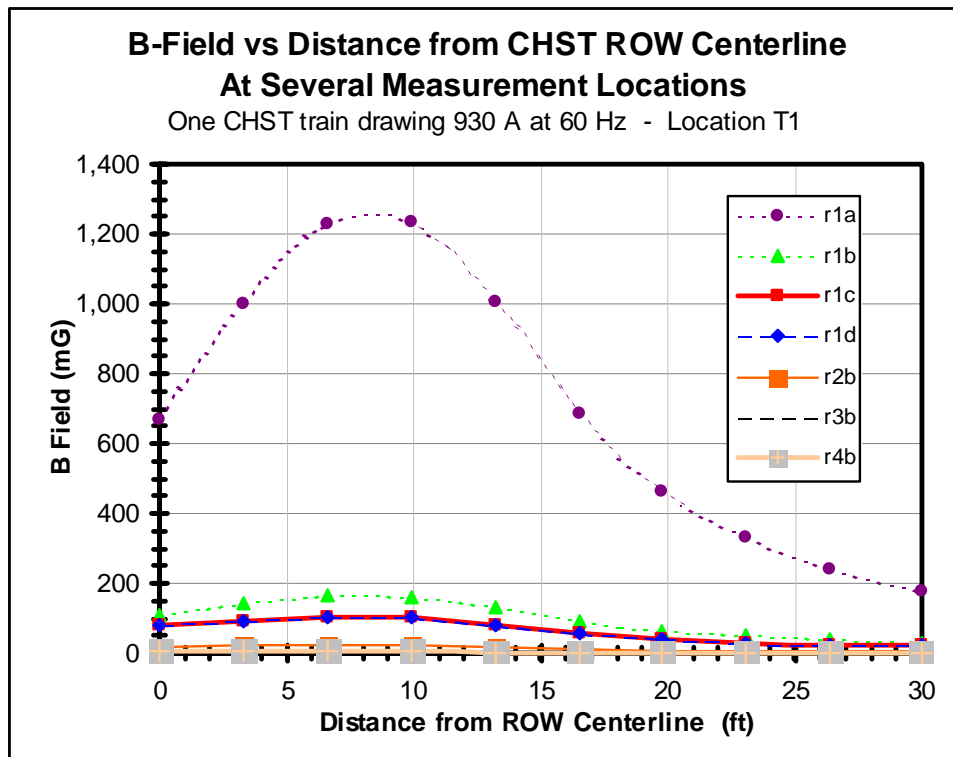
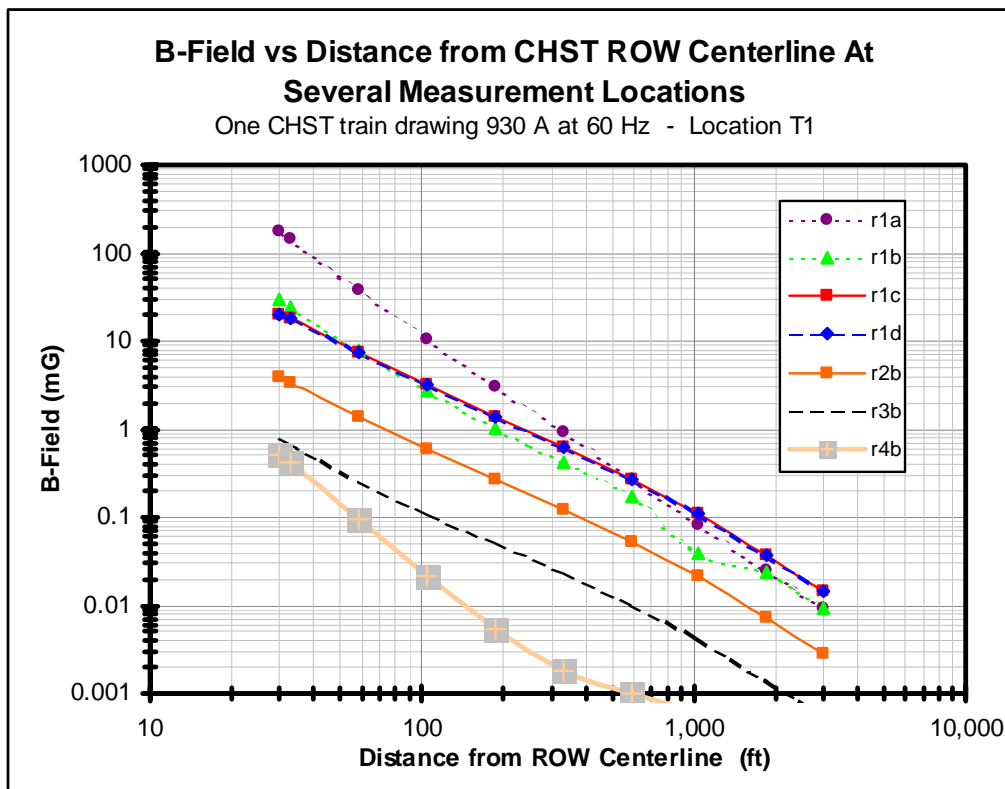


Figure 2-7b B-Fields at Several Locations Due to a 930 A Train at Location T1;  
B-Field Farther From Track





## 2.4 Comparison to Other EMFs

Two comparisons of other EMF sources to CHST B-field distances are useful:

**Overhead power line:** Southern California Edison (SCE) and other California power companies monitor and control EMF levels as required by California Public Utilities Commission (CPUC) regulations. Per SCE data in “EMF Design Guidelines For Electrical Facilities,” September 2004, a 220 kV three-phase transmission line with 1,000 A current, with the wires in the EMF-preferred configuration, will have a maximum level of 77 mG near ground level under the line. The EMF-non-preferred configuration, which is also widely used, has a maximum level of 123 mG. Utility transmission lines are a common feature in California urban, suburban, and rural environments, and people live, work, and travel near lines which have the same EMF levels as those projected for the CHST.

The 123 mG B-field for a non-preferred transmission line is similar to the worst-case B-field near the CHST fenceline.

**Measured levels on the Amtrak Northeast Corridor:** The Amtrak report “EMF Monitoring on Amtrak's Northeast Corridor: Post-Electrification Measurements and Analysis,” October 2006, states that the highest measurement on the Amtrak electrified line was 83 mG at 5 m (16.6 feet) from the track centerline; or the equivalent of 25 ft from the CHST ROW centerline. The CHST peak predicted B-fields may be higher than Amtrak measured EMFs, for several reasons:

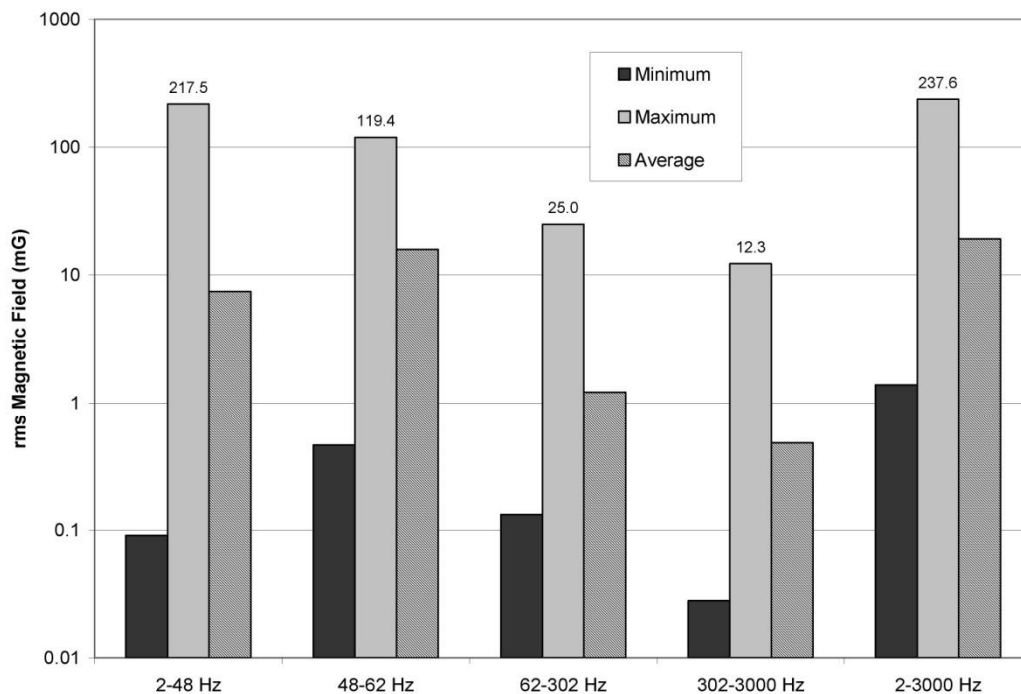
- CHST trains will operate at 220 mph, more than twice the speed of the measured Amtrak trains.
- The measured Amtrak trains were not controlled by the testers and were not drawing peak current continuously. As a result, the measurements don't represent peak EMF train conditions.

The 83 mG B-field measured for a non-worst case Amtrak train is similar to the worst-case B-field 10 feet from the CHST fenceline.

The same Amtrak report provided EMF measurements in the Acela passenger and driver's cab compartments. Figure 2-8 shows measured EMF levels in the passenger compartment. The maximum 60 Hz EMF at head height is 119 mG. Other frequencies are present from the operation of train propulsion, auxiliary, and lighting equipment.



**Figure 2-8  
Amtrak Passenger Magnetic Field Exposure Data**



**Figure 26. Chart Showing Minimum, Maximum, and Average of the Onboard Passenger Compartment Magnetic Fields by Each Frequency Band, as Measured at the Head Sensor Position**

Source: "EMF Monitoring on Amtrak's Northeast Corridor: Post-Electrification Measurements and Analysis," October 2006, Figure 26.

## 2.5 Sensitive Equipment

Whether neighbor equipment will be disturbed by CHST B-fields depends on the equipment in use by neighbors and how the equipment is protected.

The B-fields in Figures 2-7 and Figure 2-12 can be used to help determine whether a neighboring facility is close enough to the CHST ROW to be affected by CHST-generated B-fields.

Considerations are:

- The graphed B-fields are the worst-case peak magnetic field levels. At trackside locations farther from substations and at locations where trains do not draw peak current, the actual B-field vs. distance from the track will follow a curve which is significantly or dramatically lower.
  - As shown in Figure 2-7, worst-case conditions only occur at a few locations.
  - Worst case current conditions only occur a small percentage of the time.
- Whether a neighboring facility will be affected depends on the equipment in use in that facility and how the equipment is protected.



Typical susceptible equipment consists of:

- High-tech semiconductor equipment such as electron microscopes, transmission electron microscopes (TEMs) or scanning electron microscopes (SEM), electron-beam lithography, ion-writing systems, and focused ion-beam systems
- High-tech biology equipment such as nuclear magnetic resonance (NMR) systems, magnetic resonance imaging (MRI) systems, and electron microscopes
- Medical imaging equipment such as computerized tomography scanners, and MRI systems
- University/research equipment for chemistry, physics, electrical engineering, and similar systems to those mentioned for high-tech and medical facilities.

The specialized systems and equipment in these facilities require a stable magnetic field environment.

MRI machines are widely used in hospitals and clinics, and they can be disturbed by medium-low-level B-fields, unless they are shielded. Older MRI machines produce inaccurate results for ambient B-field levels greater than 3 mG; and newer, more sensitive MRIs can be affected by B-fields of 1 mG or more unless they are shielded. Most newer machines are installed in shielded rooms. Shielded MRI machines are more likely to be insensitive to ambient B-fields levels of up to 100 mG.

Specialized scientific apparatus such as NMR, SEM, and TEM are used in university and industrial research laboratories and semiconductor facilities; these require ambient B-field levels to be below the 300  $\mu$ G – 100  $\mu$ G range (0.3 – 0.1 mG). NMR, SEM, and TEM machines, especially those that are newer and more sensitive, are routinely housed in specially constructed shielded spaces designed to counteract the effects of ambient B-fields, including from the power systems that supply the machines. NMR, SEM, and TEM machines can be shielded to achieve immunity to power frequency B-fields of 10 mG or more. Because of their size and complexity, some NMR machines used in advanced research cannot be so housed and they must be located in magnetically quiet environments.

Most other equipment is unaffected by B-fields of less than 1 G.

Figure 2-2a shows that in the worst case for a single train, at distances greater than 37 feet from the ROW centerline or 7 feet from the minimum fenceline, the peak B-field will be below 100 mG. At 105 feet from the ROW centerline and 75 feet from the fenceline, the B-field will be below 10 mG.

Shielded MRI machines, even close to the CHST fence line, will probably not be exposed to CHST magnetic fields strong enough to interfere with their operation.



Even the most sensitive equipment, if shielded, will be unaffected by CHST magnetic fields at 105 feet or more from the ROW centerline. Shielded sensitive equipment will probably not be exposed to CHST magnetic fields strong enough to interfere with its operation, considering:

- The likely locations of facilities containing sensitive equipment
- Typical proximity of B-fields from utility power apparatus
- Normal practices for shielding valuable sensitive equipment

As noted above, the worst-case conditions are limited to certain places near traction power facilities, and worst-case conditions do not persist as trains move through and out of an area. The combined action of trains generates B-fields considerably lower than the worst case levels most of the time and in most places.

The information above will allow operators of sensitive medical and research to determine whether the CHST will affect their B-field environment. During the EIR/EIS process, hospitals, clinics, research facilities and high-tech industries along the proposed ROW can determine if any sensitive equipment is in use so that potential problems can be dealt with proactively.

## 2.6 Human Exposure Limits

The CHSTP will ensure that human exposure to magnetic and electric fields in and around the CHST is below the applicable limits.

The applicable documents are:

- IEEE Standard C95.6 -2002 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz [IEEE Std C95.6]
- IEEE Standard C95.1-2005 - IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz [IEEE Std C95.1]
- FCC OET Bulletin 65 Edition 91-01 - Evaluating Compliance with FCC Guidelines for Human Exposure to Radio frequency Electromagnetic Fields [FCC OET-65].

The IEEE standards, the FCC OET-65, and the CHST EMC Plan (EMCP) establish Maximum Permissible Exposure (MPE) limits both for the general population and for authorized people in controlled environments.

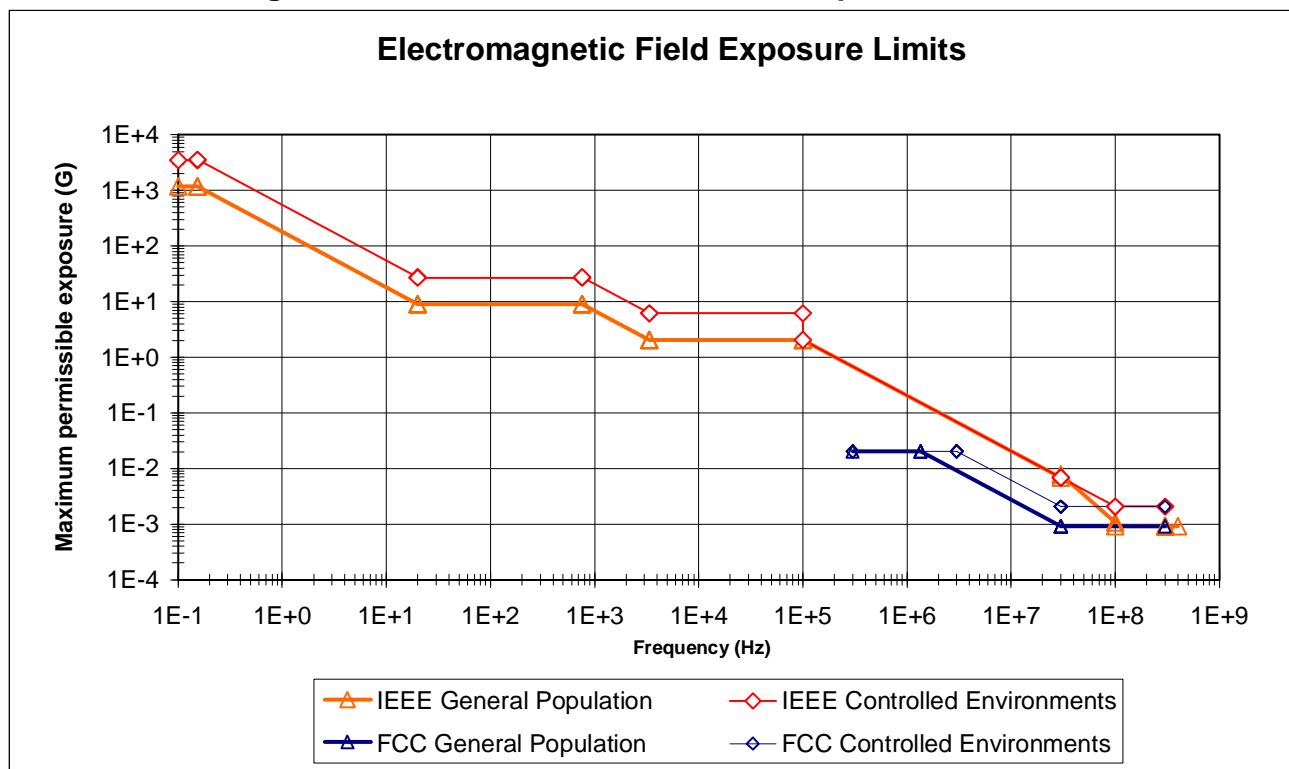
For CHST, passengers and the general public may be on station platforms and in trains. Only workers, contractors, and other authorized personnel may be in the controlled environments, such as in equipment rooms, or along the right-of-way near the tracks. The IEEE standards, FCC OET-65, and this EMDM recognize that workers and others in these controlled environments have the knowledge to minimize the duration or extent of exposure to the higher levels that may present.



For magnetic fields, the MPE limits for general public and controlled environments will conform with IEEE Std C95.6 Table 2; IEEE Std C95.1 Tables 2, 8, and 9; and FCC OET-65, Appendix A Table 1. See Figure 2-9.

At 60 Hz, the frequency of the CHST TES, the IEEE Std 95.6 Table 2 provides a MPE limit of 9.0 G (9.0 mT) for the general public. As shown in Figure 2-2a, a person on a CHST passenger platform, at about 8 feet from the track centerline or 16 feet from the ROW centerline, will be exposed to a worst-case B-field of about 720 mG from a single train. Thus, the CHST worst-case human exposure will be about 7.9% of the applicable MPE limit. However, CHST design criteria call for Substations to be positioned at least 2 miles from any passenger station. The maximum B-field at a location 2 miles from a Substation will be considerably less than the worst-case B-field, so the maximum platform exposure for a CHST passenger will be less than 720 mG / 7.9% of MPE.

**Figure 2-9**  
**Magnetic Field Maximum Permissible Exposure Limit**



## 2.7 Implanted Medical Device Limits

Implanted medical device manufacturers and U.S. research laboratories have established exposure limits for people with implanted medical devices such as pacemakers. The recommended limit is 1.0 G for frequencies up to 10 kHz, including the CHST traction power frequency of 60 Hz.

EMF levels above the recommended 1.0 G limit may exist inside traction power facilities. TPF sites will be normally unmanned; workers will enter only periodically, for example, to perform routine maintenance. The CHST safety program will disclose health risks to employees who have implanted medical devices and will preclude workers with implanted medical devices from entering any TPF with levels above the recommended limits.

The CHST project will determine whether an EMF level above the recommended 1.0 G limit can occur inside the rolling stock passenger compartments. During rolling stock design and construction, the project will perform a detailed design assessment to determine worst case level EMF levels inside the passenger compartment, considering the worst case EMF due to OCS and rail currents and the shielding effect of the railcar body. After construction, the project will test the rolling stock to determine the actual worst case EMF level inside the passenger compartment.

The CHST project will determine whether an EMF level above the recommended 1.0 G limit can occur on passenger station platforms. If the actual EMF levels exceed the established limit, the CHST safety program will ensure that passengers and employees who have implanted medical devices are informed of the condition by placing suitable warning signs on the passenger station platforms, indicating areas where passengers and employees with pacemakers can stand or sit without exposure to EMF levels above the recommended limits.

## 2.8 Criteria for Impact Assessment

### 2.8.1 Significance Criterion

The CHST project has set a significance criterion of 2 mG for environmental assessment. During the EIR/EIS work, the CHST regional consultants will evaluate land uses out to the distance from the near track centerline to the distance at which the worst-case B-field from a single CHST train is less than 2 mG.

Per Figure 2-2b, the distance from the ROW centerline to the place where the B-field will drop below the significance criterion of 2 mG for a single train drawing 930 A at 60 Hz is about 226 feet. Since the ROW centerline is generally at least 30 feet from the fenceline, the significance criterion extends out about 200 feet from the CHST fence.



The basis for setting the significance criterion at 2 mG is:

- The significance criterion is 1/4500<sup>th</sup> of the human B-field Maximum Permissible Exposure (MPE) level.
- The significance criterion is roughly equivalent to the susceptibility level of an unshielded MRI machine. MRI machines are broadly used, although new MRI machines are generally shielded.
- The 2 mG criterion is a typical level emitted from household appliances, so it is broadly recognized as a common environmental condition.

### **2.8.2 Local Ambient Level**

The CHST will operate through urban, suburban, rural, mountain, and desert terrain.

Along its route, the CHST will pass close to, cross, and run alongside typical emitters of strong B-fields, including utility power transmission and distribution lines; industrial, commercial, airport, and government sites with significant electrical power use; and radio transmitters and other energetic EMI/EMF sources. Where the CHST will pass close to other high power and high current equipment and facilities, the local ambient B-field will already be high and the CHST B-field will not significantly affect the ambient B-field.

In other parts of its route, the CHST will operate in residential areas and in sparsely populated land which is either not developed or is used for agriculture. In those areas, the CHST B-field will be greater than the local ambient level. However, the B-field will not be significant because residential, undeveloped, and agricultural land and occupants are not sensitive to or affected by B-fields of the levels shown in Figure 2-2b.

When performing EMF footprint assessments, the section team should be alert for potentially sensitive equipment as described in section 2.6 in an area not otherwise exposed to typical urban and power distribution line B-field levels.





### 3 Magnetic Field Calculation Model

This section describes the calculation of B-field vs. lateral distance from the CHST track centerline. The calculation model can determine the effect of a single train anywhere in a typical CHST section of track, considering the distances, speeds, and traction power section lengths. The model can also use the results of CHST project simulations to calculate the effects of a set of trains in full revenue service.

#### 3.1 Traction Electrification System

Figures 2-1a and 2-1b above are an overview of the CHST 2x25 kV 60 Hz TES, per TM 3.1.1.1, Traction Power 2x25kV Autotransformer Feed Type Electrification System and System Voltages. As noted above, the Traction Electrification System (TES) traction power facilities are Substations every 30 miles, Switching Stations (SS) every 15 miles between Substations, and Paralleling Stations (PS) every 5 miles. There are section breaks at each Substation and SS.

PSs, SSs, and Substations each provide a connection between the static wire (aerial ground), running rails, and ground. The ground contact resistance is a maximum of 5 ohm, but is typically less than 1 ohm. The static wire is electrically connected to each catenary pole, and each pole is grounded with a contact resistance of about 25 ohm. The rails sit on insulated pads and the rail clips are insulated; resistance between running rails and ground is expected to be at the high end of the conventional range of 1 to 20 ohm-km.

The figure also shows “A-point” crossbond locations. A-points provide static wire-to-rail-to-ground connections. In the section between Substation U2 and SS2-3, there are two A-points between each traction power facility, every 1.67 miles. The actual spacing of “A-points” for the CHST line has not been finalized.

Figure 3-1 shows the planned CHST OCS arrangement.

#### 3.2 SPICE Model

Tenco created a SPICE (Simulation Program with Integrated Circuit Emphasis) model for calculating the currents in CHST OCS and running rail conductors for various train locations and ROW conditions. The SPICE model is organized into sections which include the Substations, the section including the train, and sections of variable length in front of and behind the train which connect the train section to the Substations. Figure 3-2a and 3-2b comprise an overview of the SPICE model. It models the section of track between Substations U2 and U3 in Figure 2-1a and 2-1b. Table 3-1 shows the physical arrangements of conductors in Figure 3-2a and 3-2b, consistent with the Figure 3-1a and 3-1b CHST directive drawings.

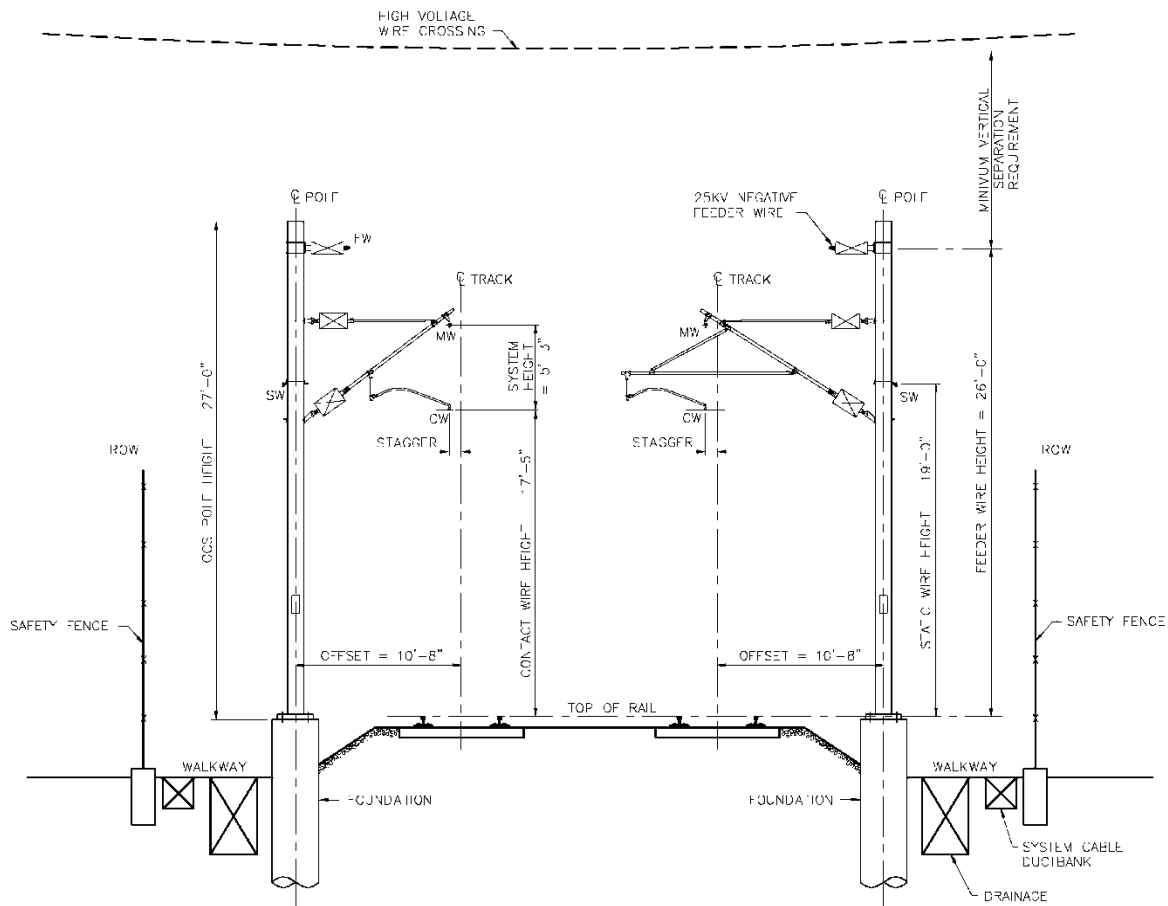




The model incorporates resistances and self-inductances of all conductors running down the ROW, including a model ground conduction path, as well as spreadsheet results for all mutual inductances of the conductors. The model also incorporates circuit models of the power transformers, autotransformers, ground contact resistances, and the AC power source. Spreadsheets use the calculated currents to determine B-fields and E-Fields.

The Tenco model for EMF calculation model assumes a train peak power use is 23.3 MVA, or about 930 A at 25 kV.

**Figure 3-1a Overhead Contact Wire Conductors**



**Notes:**

**[1] Legend:**

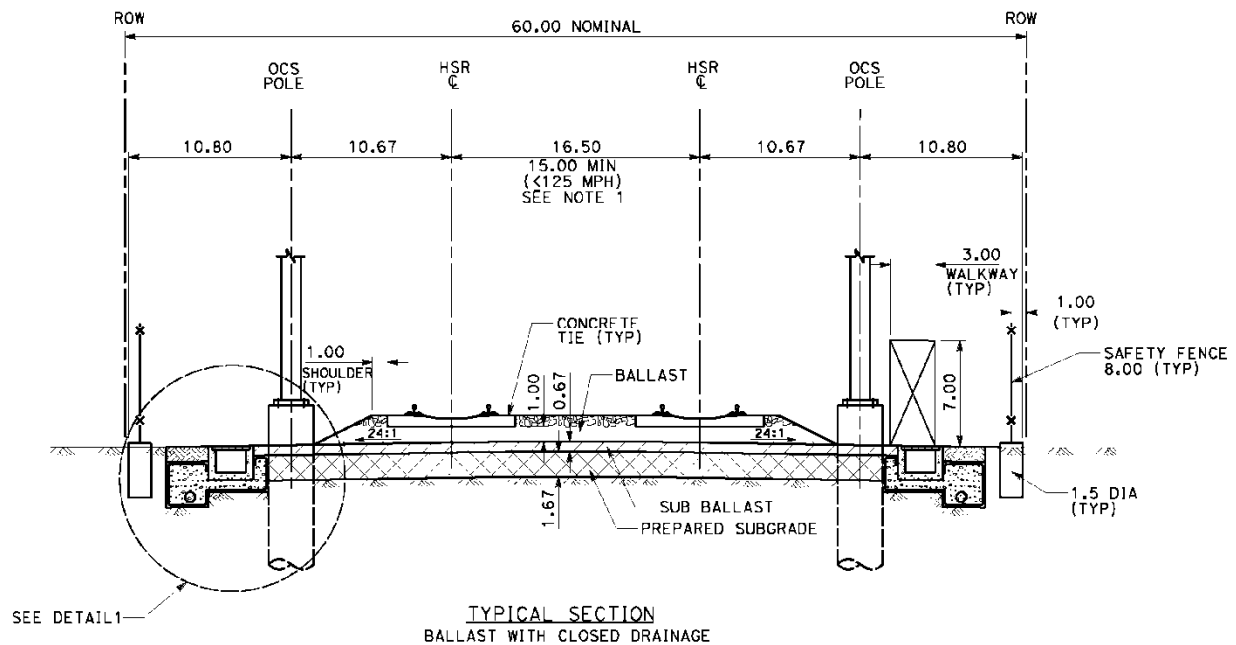
**LEGEND:**

|         |                           |
|---------|---------------------------|
| FW      | NEGATIVE FEEDER WIRE 25KV |
| SW      | STATIC WIRE               |
| MW      | MESSENGER WIRE            |
| CW      | CONTACT WIRE              |
| SE      | TRACK SUPERELEVATION      |
| HRLH 3H | RAIL LEVEL                |
| CL      | CENTERLINE                |
| TOR     | TOP OF RAIL               |
| ROW     | RIGHT OF WAY              |

**[2] Conductor characteristics:**

- Contact Wire: 150 sq mm., 13.6 mm dia. (CuMg 0.5)
- Messenger Wire: 150 sq mm (300 kcmil) (CuOF)
- Negative Feeder: 228 sq. mm., 20.5mm dia. (ACSR)
- Static Wire: 93 sq. mm., 12.5mm dia. (ACSR)



**Figure 3-1b Track and OCS Dimensions****Table 3-1 CHST OCS Conductor Locations**

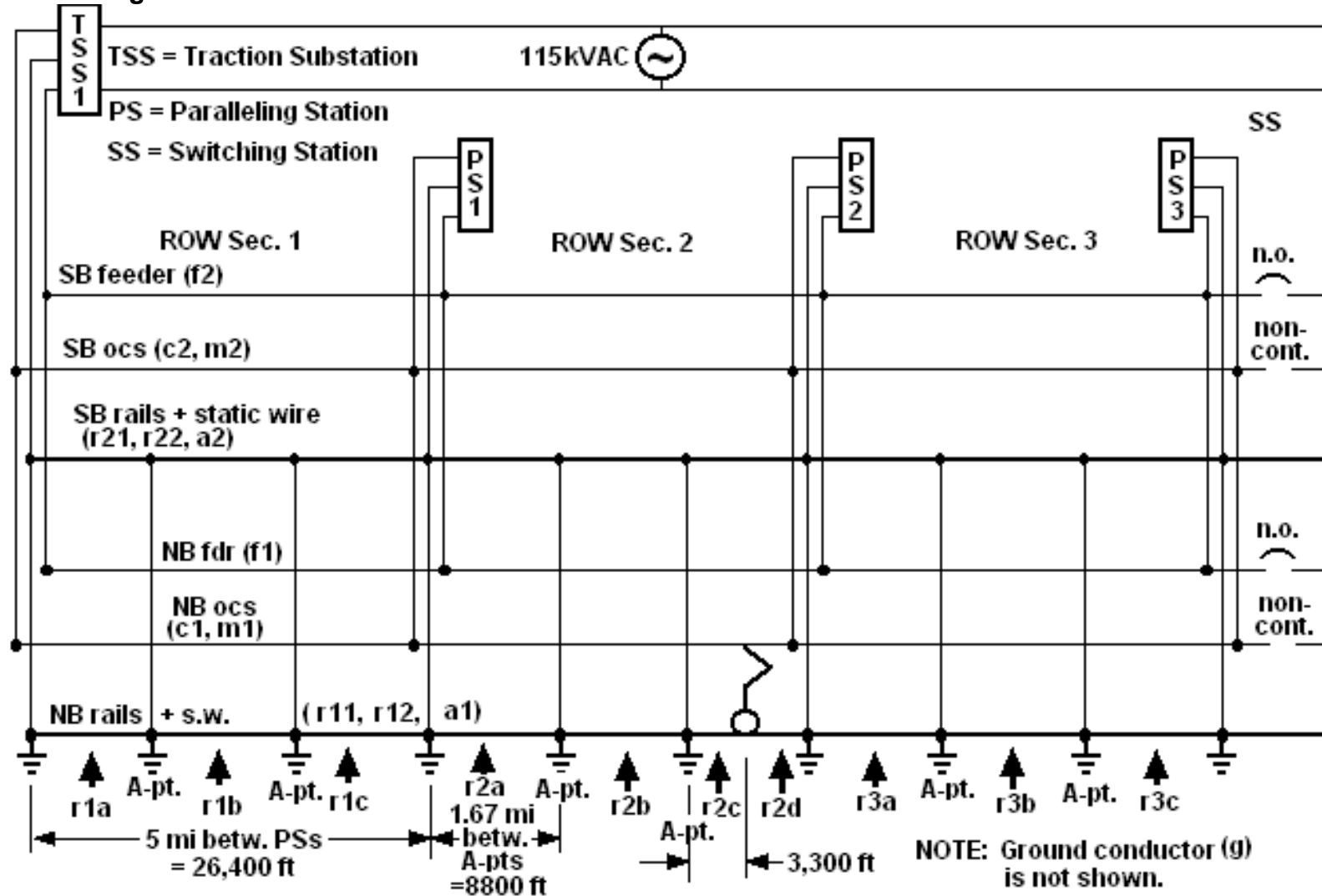
| conductor        | x-horiz ft | y-vert ft | x-horiz m |  | y-vert m |
|------------------|------------|-----------|-----------|--|----------|
| <b>r11</b>       | -10.66     | 0.00      | -3.25     |  | 0.00     |
| <b>r12</b>       | -5.74      | 0.00      | -1.75     |  | 0.00     |
| <b>cw1</b>       | -8.20      | 17.48     | -2.50     |  | 5.33     |
| <b>m1</b>        | -8.20      | 21.98     | -2.50     |  | 6.70     |
| <b>nf1</b>       | -17.26     | 25.91     | -5.26     |  | 7.90     |
| <b>aec1 = a1</b> | -19.26     | 19.02     | -5.87     |  | 5.80     |
| <b>r21</b>       | 5.74       | 0.00      | 1.75      |  | 0.00     |
| <b>r22</b>       | 10.66      | 0.00      | 3.25      |  | 0.00     |
| <b>cw2</b>       | 8.20       | 17.48     | 2.50      |  | 5.33     |
| <b>m2</b>        | 8.20       | 21.98     | 2.50      |  | 6.70     |
| <b>nf2</b>       | 17.26      | 25.91     | 5.26      |  | 7.90     |
| <b>aec2 = a2</b> | 19.26      | 19.02     | 5.87      |  | 5.80     |

**Key to Conductors:**

- r11, r12 = track 1 running rails.
- cw1 = track 1 contact wire. (also labeled c1 in following figures)
- m1 = track 1 messenger.
- nf1 = track 1 negative feeder. (also labeled f1 in following figures)
- a1 = aec1 = track 1 static wire, aerial wire, or aerial earthing conductor.



Figure 3-2a SPICE Model of Train and Overhead Contact Wire Conductors – Left Half



Model of a 30 mile section of the CHST ROW between main power feed points. The figure shows the locations along ROW at which 60 Hz B-fields were calculated. Differences in the distribution of currents between conductors make B-fields greater at location r1b than at any of the others. Note that PS3 and PS4 are located in the same building.



**Figure 3-2b SPICE Model of Train and Overhead Contact Wire Conductors – Right Half**